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LUNAR ORBIT RENDEZVOUS REFERENCE TRAJECTORY DATA PACKAGE (U)

PREPARED UNDER CONTRACT NO. 10001
TO BELLCOMM, INC.

PROPOSED FORMAT FOR RTDP ISSUE 4

8404-6047-RC-000 **APRIL 15, 1964**

Classification changed to UNCLASSIFIED by authority of SCG-11, Rev. 1, 1/1/66, and SCG-6, 8/27/64, as amended.
Initials: MM Date: 3/28/69
See letter dated 3/11/69 from R. L. Wagner

TRW SPACE TECHNOLOGY LABORATORIES
THOMPSON RAMO WOOLDRIDGE INC.

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from R. L. Wagner's letter dated 3-11-69

Approved: F. L. Baker
F. L. Baker
Project Manager

Approved: Edward M. Boughton
E. M. Boughton
Assistant Director for Projects
Mission Analysis and Simulation
Laboratory

TRW SPACE TECHNOLOGY LABORATORIES
Thompson Ramo Wooldridge Inc.
One Space Park · Redondo Beach, California

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I. INTRODUCTION

This document describes the format which STL intends to use in the publication of RTDP Issue 4 as provided by subcontract No. 10001, Amendment No. 3 from Bellcomm, Incorporated. Issue 4 is to contain five Apollo trajectory simulations and supporting material presented in a manner similar to that of references 1 through 4. In general, the format of Issue 4 will be the same as references 1 through 4, multiplied by five, except with respect to the specific revisions suggested below.

II. GENERAL ORGANIZATION

Issue 4 will be published as a set of twenty, permanent-bound, confidential volumes. Each trajectory will be comprised of four volumes. Trajectory No. 1, for example, will be presented as follows:

Volume 1A - Summary and Reference Trajectory No. 1 Data Exhibits

Volume 1B - Printout Keys and Reference Trajectory No. 1 Listing (Earth Launch to LEM Final Descent)

Volume 1C - Reference Trajectory No. 1 Listing (LEM Final Descent to Earth Reentry)

Volume 1D - Reference Trajectory No. 1 Listing (Reentry)

Trajectory No. 2 will begin with Volume 2 and so on.

III. SPECIFIC ORGANIZATION

1. The Volume A Series

Each Volume xA will contain an introduction followed by five major sections. The introduction will provide a general qualitative description of the trajectory under consideration and its important features will be highlighted.

Section 1: Mission Profile - This section will be devoted to the same material, which will be presented in the same format, as pp. 4-20 of reference 1. This section contains descriptions, in some detail, of the major mission phases with regard to the behavior of the trajectory being documented. Eight subsections are designated 1.1 through 1.8.

Section 2: Sequence of Trajectory Events - This section will be identical to pp. 21-27 of reference 1 with respect to format. It will consist of a single table noting the time (reckoned three ways) of trajectory events and a description of those events. The first time base will be Greenwich Mean Time (GMT) given as day, month, year, hour, minute, and second (at least to the nearest tenth). The second time base will be total elapsed time in minutes from lift-off at Cape Kennedy. The third time base will usually be the elapsed time of a major mission phase. Time in this mode is initialized with each major phase. Trajectory parameter histories given in section 5 will generally use this last method of reporting time.

Section 3: Summary of Input Information - This section will contain the same material as in section 3 of reference 1 except subsection 3.3.4 thereof which will be incorporated in section 4. The summary of input information will set forth all numerical data used as inputs to the trajectory simulation such as vehicle and spacecraft weight and propulsion data, aerodynamic data, tracking network information, astrodynamic constants, a lunar ephemeris covering the time interval of each trajectory, and general system constraint data. It is anticipated that, with the exception of the lunar ephemeris, the data presented in this section will be the same for all trajectories. It will be repeated in each Volume xA for convenience of reference.

Section 4: Mission Constraints and Analysis - This section will contain two specialized subsections; mission constraints and trajectory selection, and powered flight optimization. Since Issue 4 reference trajectories are to be designed respecting a number of mission constraints and groundrules, the first subsection will discuss these with regard to the included trajectory. Insofar as practicable, data will be presented to show the effects on constraints of having chosen other values for the free trajectory variables. These data will be of the nature of first-order tradeoff coefficients and will hopefully give some perspective to the particular mission profile being documented. This subsection will attempt to summarize trajectory selection information such as launch windows, velocity and/or propellant requirements, lunar landing site accessibility, LEM plane change restrictiveness, and the transearth trajectory/reentry maneuver angle/earth landing site interaction. As an example of the general intent of this subsection, the documented trajectory may have been chosen deliberately to illustrate the effects of a "bad" choice of mission plan compared to a more favorable selection for the same mission objective. In the larger sense, the package of five trajectories will attempt to demonstrate the effects of gross changes in mission plan such as free return versus non-free return.

Each powered flight phase of the trajectory will be optimized (minimum propellant consumption) within propulsion system constraints and mission objectives. Therefore, a subsection will be devoted to reporting these results even though the separate optimizations are not likely to change from trajectory to trajectory.

Section 5: Reference Trajectory Data Exhibits - This section will be essentially identical with section 5 of reference 1. It will contain eight subsections of plots, usually versus time, of many trajectory parameters plus a discrete events table summarizing a few parameters of each principal trajectory phase. At the present time, the following functions will be plotted in addition to those in sections 5, 7, and 8 of reference 1.

a) In all free flight phases except earth parking orbit and reentry (subsections 5. 3 through 5. 7):

   1) Sun-vehicle-moon angle versus time

   2) Sun-vehicle-earth angle versus time

b) In the LEM descent and ascent phases (subsection 5. 5):

   1) LEM ascent plane change requirement versus time

   2) Azimuth of sun from landing site versus time

   3) Elevation of sun from landing site versus time

The majority of these functions will be machine plotted in contrast to the hand-drawn method used in reference 1. A sample of a machine plotted graph is included as figure III-1. As necessary, notes will be added to these plots to make them at least as complete as before.

Volume xA will conclude with a list of references for data used in the trajectory selection and simulation.

2. <u>The Volume B Series</u>

Each Volume xB will contain an introduction to the reference trajectory printout, a printout symbol list and definitions thereof, and approximately one-half of the reference trajectory printout.

The introduction will highlight some of the quantitative characteristics of trajectory (see reference 2).

The printout symbol list provides the general layout of the reference trajectory printout according to the applicable trajectory phases. Following the symbol grid, definitions of all quantities are described and, as needed, figures are included for clarification. A tentative symbol list with definitions and figures is provided at the end of this document. Compared with reference 2, the new symbol format contains additional functions to assist in evaluation of adherence to the current set of trajectory constraints plus some quantities which may be of general interest (e.g., eclipse of the spacecraft by the moon). New or relocated functions are indicated by an asterisk.

The trajectory listing concluding this volume begins at lift-off and will tentatively end at the point where the LEM begins the powered descent from 50,000 feet to the lunar surface. Approximately eleven tab dividers will be inserted to assist in rapid location of particular trajectory phases.

3. <u>The Volume C Series</u>

Each Volume xC will continue the trajectory listing to the reentry point and will thus include all of reference 3 and most of reference 4. Approximately six tab dividers will be provided.

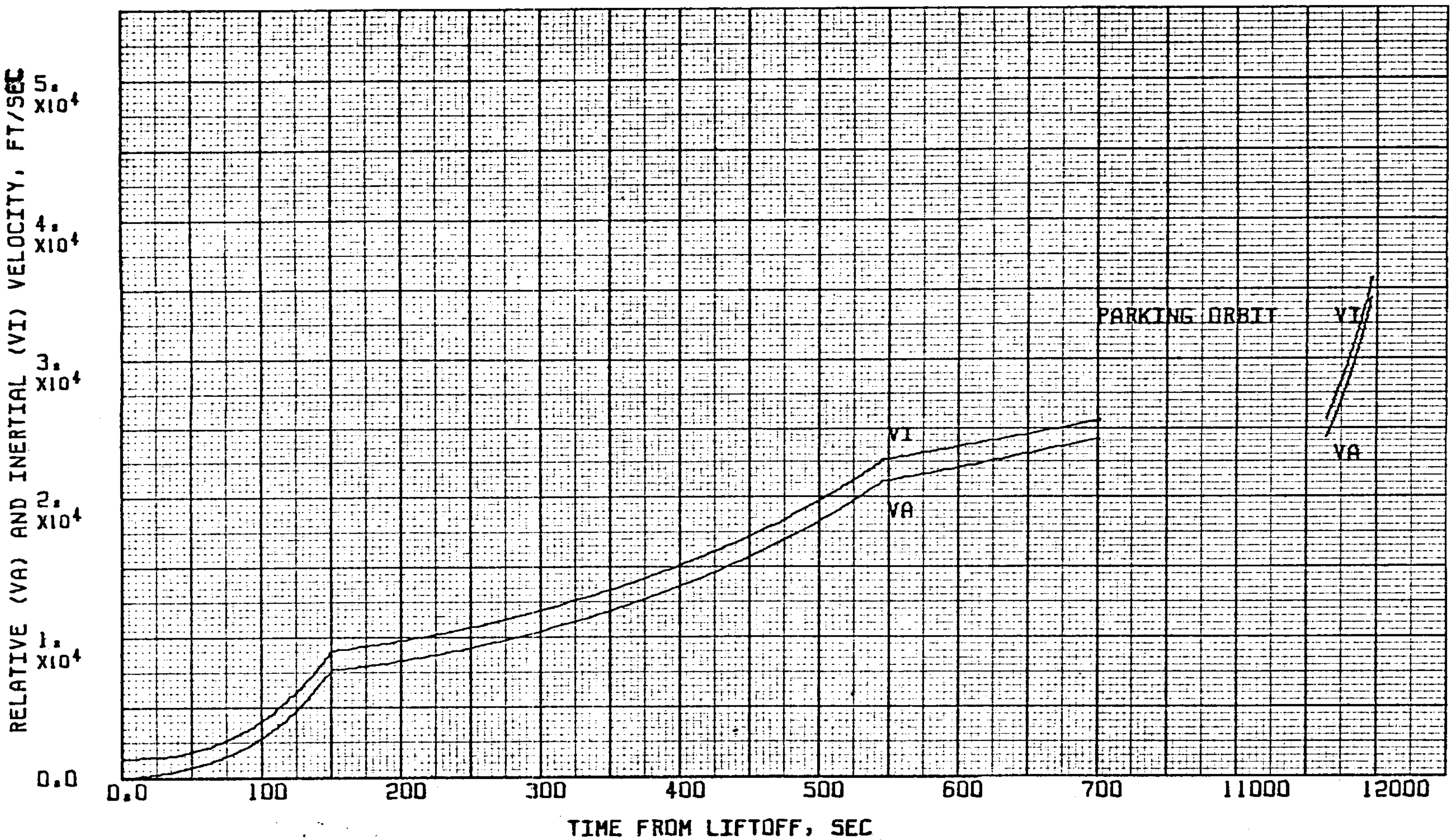


Figure III-1. Earth Launch and Translunar Injection - Relative (VA) and Inertial (VI) Velocity

4. The Volume D Series

Each Volume xD will contain the reentry trajectory listing. Reentry will be simulated according to the simple lift management through roll control scheme developed for RTDP Issue 2.

REFERENCES

STL Report, "Lunar Orbit Rendezvous Reference Trajectory Data Package -- Issue 2," dated 30 September 1963.

1. Volume 1 - Document No. 8408-6023-RC-000
2. Volume 2 - Document No. 8408-6024-RC-000
3. Volume 3 - Document No. 8408-6025-RC-000
4. Volume 4 - Document No. 8408-6026-RC-000

Earth Powered Flight and Reentry Phases

Symbol Grid I

T

GEOCENTRIC

	ALT	R	VI	X	VX
	LTDM	RASC	FPVI	Y	VY
	LONM	DECL	AZVI	Z	VZ
	A	ASND	VVEN	APOG	VAPG
	ECC	ARGP	ARGL	PERG	VPER
	INCL	MA	TA	PERD	BODY CONIC
(note 1)	TIMP	LTDI	LONI	CRIP	VIRE
	WT	ATLI	VA	AAAP	VIR
	DVV	AMIS	FPVA	AAAY	VIT
	RANG	RLAT	AZVA	AAAT	VAT
	ANCR				
(note 2)	LFTN	LFTL			
(note 3)	DRG	Q	MACH	SS	ADEN
(note 3)	FN	QAL	ADH	ATEM	APSI
(note 4)	F	DWT		VISN	DVI
(note 5)	UL	DUL	PXG	VXG	AXG
	VL	DVL	PYG	VYG	AYG
	WL	DWL	PZG	VZG	AZG

Earth Powered Flight and Reentry Phases

Symbol Grid I (Continued)

(note 6)	RDR nn	RGR	AZR	ELR	DRGR
	RLA1	RLA2	LAP	LAY	LAPP
	DPR	DQR	DAZR	DELR	
	PICH	PAT	XIX	ETX	
	YAW	YAT	XIY	ETY	
	ROLL	RAT	XIZ	ETZ	

(note 1) This line of output printed only when vehicle perigee altitude is negative. When printed, previous two lines of output are deleted.

(note 2) This line of output printed only in earth reentry phase.

(note 3) These two lines of output deleted when vehicle is above earth's atmosphere.

(note 4) This line of output deleted during all free-flight phases.

(note 5) This block of output deleted when vehicle goes below horizon relative to launch sites.

(note 6) This block of output deleted when vehicle goes below horizon relative to radar site.

Translunar and Transearth Free Flight (Geocentric Phase)

Symbol Grid II

T

GEOCENTRIC

ALT	R	V̇I	X	VX
LTDM	RASC	FPVI	Y	VY
LONM	DECL	AZVI	Z	VZ
A	ASND	VVEN	APOG	VAPG
ECC	ARGP	ARGL	PERG	VPER
INCL	MA	TA	PERD	BODY CONIC
XMN	YMN	ZMN		
WT	DVV			
XP	ELAT	ELK	VERA	VEDC
YP	ELON	SLK	VSRA	VSDC
(NOT) ECLIPSED	(NOT) VISIBLE*	TLK	VTRA	VTDC
SEM*	SME*	SVM*		
MEV*	EMV*	MVE*		
VES*	VMS*	EVS*		

STAR	RASC	DECL	EVST	MVST	SVST	BAVST	VVST

*new or relocated function

Translunar and Transearth Free Flight (Selenocentric Phase)

Symbol Grid III

T

GEOCENTRIC

	ALT	R	VI	X	VX
	LTDM	RASC	FPVI	Y	VY
	LONM	DECL	AZVI	Z	VZ
	A	ASND	VVEN	APOG	VAPG
	ECC	ARGP	ARGL	PERG	VPER
	INCL	MA	TA	PERD	BODY CONIC
	XMN	YMN	ZMN		
SELENOGRAPHIC					
	ALT	R	VI	X	VX
	LTDM		FPVI	Y	VY
	LONM		AZVI	Z	VZ
	A	ASND	VVEN	APOG	VAPG
	ECC	ARGP	ARGL	PERG	VPER
	INCL	MA	TA	PERD	BODY CONIC
	LTDE	LONE	LTDS	LONS	
	VINF*	ALIN*	DLIN*	THIN*	TFFI*

*new or relocated function

Translunar and Transearth Free Flight (Selenocentric Phase)

Symbol Grid III (Continued)

SELENOCENTRIC

ALT	R	VI	X	VX
LTDM		FPVI	Y	VY
LONM		AZVI	Z	VZ
A	ASND	VVEN	APOG	VAPG
ECC	ARGP	ARGL	PERG	VPER
INCL	MA	TA	PERD	BODY CONIC
WT	DVV			
VINF	THIN	B	DCA	
ALIN	TFFI	B · T	TCA	
DLIN		B · R	TMFL	
XP	ELAT	ELK	VERA	VEDC
YP	ELON	SLK	VSRA	VSDC
(NOT) ECLIPSED	(NOT) VISIBLE*	TLK	VTRA	VTDC
SEM*	SME*	SVM*		
MEV*	EMV*	MVE*		
VES*	VMS*	EVS*		

STAR RASC DECL EVST MVST SVST BAVST VVST

*new or relocated function

Lunar Powered Flight and Coast Phases

Symbol Grid IV

	T				
SELENOGRAPHIC					
	ALT	R	VI	X	VX
	LTDM		FPVI	Y	VY
	LONM		AZVI	Z	VZ
	A	ASND	VVEN	APOG	VAPG
	ECC	ARGP	ARGL	PERG	VPER
	INCL	MA	TA	PERD	BODY CONIC
(note 1)	TIMP*	LTDI*	LONI*	CRIP*	
	LTDE	LONE	LTDS	LONS	AZS*
	EARTH IS (NOT) VISIBLE*		VEHICLE IS (NOT) ECLIPSED*		ELS*
	SEM	SME	SVM		
	MEV	EMV	MVE		
	VES	VMS	EVS		
	WT	ATLI	VA	AAAP	VIR
	DVV	AMIS	FPVA	AAAY	VIT
	RANG	RLAT	AZVA	AAAT	VAT
	ANCR				
(note 2)	F	DWT		VISN	DVI
	VLGR	VLML	ASPM	TPSE	IDVL
(note 3)	PICH*	YAW*	ROLL*		
(note 4)	RDR nn	RGR	AZR	ELR	DRGR
(note 5)	ACSM*	ECSM*	CSM IS (NOT) VISIBLE*		
(note 6)	DELI*	AZLO*			

*new or relocated function

Lunar Powered Flight and Coast Phases

Symbol Grid IV (Continued)

COORDINATES OF LEM RELATIVE TO CM-SM

TMST	RCL	OPCL	XCL	VXCL
	ACL	DRCL	YCL	VYCL
	ECL		ZCL	VZCL

(note 1) Analytical instantaneous impact quantities are printed only when the perifocal attitude is less than or equal to zero (that is, when the vehicle is on an impacting trajectory), replacing the preceding two lines.

(note 2) Deleted during free-flight phases.

(note 3) Deleted when all the rates are zero.

(note 4) Printed throughout the LEM descent and ascent powered flight phases.

(note 5) Printed from beginning of LEM lunar descent to rendezvous.

(note 6) Printed during LEM lunar stay period.

COORDINATE SYSTEMS

Geocentric, X-Y-Z

Inertial, right-handed orthogonal system with the origin at the center of the earth and oriented such that the X-Y plane contains the earth's true equator of date, the positive X axis points in the direction of the true vernal equinox of date, the Z axis coincides with the earth's spin axis, and the Y axis completes the right-handed system.

Selenocentric, X-Y-Z

Inertial, right-handed, orthogonal system with the origin at the center of the moon and oriented such that the X-Y plane is parallel to the earth's true equator of date, the positive X axis points in the direction of the true vernal equinox of date, the Z axis is parallel to the earth's spin axis, and the Y axis completes the right-handed system.

Selenographic, X-Y-Z

Right-handed, orthogonal system with the origin at the center of the moon and the coordinate axes fixed in the moon such that the X-Y plane contains the moon's equator, the positive X axis passes through the Sinus Medii (Central Bay) on the lunar surface, the Z axis coincides with the moon's spin axis, and the Y axis completes the right-handed system.

Topocentric launch site fixed, UL-VL-WL

Right-handed, orthogonal system in which the origin coincides with the launch site, the positive UL axis extends downrange in the direction of the launch azimuth, the positive VL axis extends to the left in a direction orthogonal to the downrange direction, and the positive WL axis extends upward in the direction of the astronomical vertical, the UL-VL plane thus being coincident with the plane of the astronomical horizon.

Topocentric inertial, PXG-PYG-PZG

Right-handed, orthogonal system fixed in inertial space and oriented such that the system coincides with the above defined UL-VL-WL system at the instant of liftoff.

Vehicle Fixed

Right-handed, orthogonal system fixed in the vehicle and oriented such that the thrust vector is aligned along the positive roll axis and the pitch and yaw axes complete the right-handed system as defined in Figure 1. Note that the positive directions of pitch, yaw, and roll are defined.

CSM centered relative, XCL-YCL-ZCL

Left-handed, orthogonal system centered at the CSM and oriented such that the positive ZCL axis points in the outward radial direction of the selenocentric radius vector to the CSM, the positive XCL axis lies in the CSM orbital plane and is oriented 90 degrees ahead of the positive ZCL axis in the direction of orbital motion of the CSM, and the positive YCL axis is normal to the CSM orbital plane and completes the left-handed system. The relative coordinate system and the angles measured therein are defined in Figure 2.

Target centered, S-T-R

Right-handed, orthogonal system with the origin at the center of the target body and oriented such that the positive S axis points in the direction of the velocity vector from infinity, V_{∞}; the T axis is the intersection of the moon's orbit plane and the plane which contains the center of the target body and which is normal to the S axis, the positive sense of which is defined by $\overline{T} \equiv \overline{S} \times \overline{W}$, where $\overline{W}$ points in the direction normal to the moon's orbit plane; and the positive R axis completes the right-handed system through the relationship, $\overline{R} \equiv \overline{S} \times \overline{T}$ as defined in Figure 3.

Greenwich inertial, X-Y-Z

Inertial, right-handed, orthogonal system with the origin at the center of the earth and oriented such that the X-Y plane contains the earth's true equator of date, the positive X axis passes through the Greenwich meridian at the instant of liftoff, the Z axis coincides with the earth's spin axis, and the Y axis completes the right-handed system.

SYMBOL	DEFINITION
A	Orbital semi major axis (feet).
AAAP*	Pitch angle of attack, measured in the vehicle fixed coordinate system from the positive roll axis to the relative velocity vector projected into the pitch plane, measured negative in the direction of the positive yaw axis (degrees).
AAAY*	Yaw angle of attack, measured in the vehicle fixed coordinate system from the positive roll axis to the relative velocity vector projected into the yaw plane, measured negative in the direction of the positive pitch axis (degrees).
AAAT*	Total angle of attack, the in-plane angle measured in the vehicle fixed coordinate system from the positive roll axis to the relative velocity vector (degrees).
ACL	Azimuth of the relative range vector from the CSM to the LEM, measured in the XCL-YCL plane clockwise from the positive XCL axis to the projection of the relative range vector upon the XCL-YCL plane (degrees). See Figure 2.
ACSM	Central angle between the selenocentric radius vectors to the LEM and CSM (degrees).
ADEN	Air density (slugs per cubic foot).
ADH	$\int Q\, VA \cdot dt$; aerodynamic heating (pounds per foot).
ALIN	Right ascension (longitude) of the velocity vector from infinity in the selenocentric (selenographic) coordinate system (degrees).
ALT	Altitude above the reference ellipsoid of the central body along the radius vector (feet).
AMIS	Azimuth from north of the vehicle roll axis projectea on a plane normal to the radius vector (degrees).
ANCR	Central angle from the current vehicle position to the launch (target) site (degrees).
APOG	Apofocal altitude above the reference ellipsoid of the central body along the radius vector to the apofocus (nautical miles).

* See Figure 1.

SYMBOL	DEFINITION
APSI	Atmospheric pressure (pounds per square inch).
ARGL	Osculating orbital argument of latitude (degrees).
ARGP	Osculating orbital argument of perifocus (degrees).
ASND	Right ascension of the ascending node in geocentric and selenocentric print block, longitude of ascending node in selenographic print block (degrees).
ASPM	Average specific impulse per primary stage (seconds).
ATEM	Air temperature (degrees Rankine).
ATLI	Attitude angle between the local radius vector and the vehicle roll axis (degrees).
AXG AYG AZG	Components of the total acceleration vector in the topocentric inertial coordinate system (feet per second per second).
AZLO	Required LEM launch azimuth, measured positive clockwise from north (degrees). See Figure 4.
AZR	Azimuth of the radar-to-vehicle line-of-sight projected on a plane normal to the astronomic vertical at the radar site, measured clockwise from north (degrees).
AZS	Azimuth from north of the selenocentric radius vector to the sun projected onto a plane normal to the radius vector to the landing site (degrees).
AZVA	Azimuth from north of the relative velocity vector projected on a plane normal to the radius vector (degrees).
AZVI	Azimuth from north of the inertial velocity vector projected on a plane normal to the radius vector (degrees).
B*	Magnitude of the impact parameter vector (feet).
B· T*	Component of the impact parameter vector along the T axis in the target centered STR coordinate system (feet).

* See Figure 3.

SYMBOL	DEFINITION
B · R*	Component of the impact parameter vector along the R axis in the target centered STR coordinate system (feet).
BAVST	Body-axis-vehicle-star angle, i.e., the look angle measured from the positive roll axis of the vehicle to the radius vector from the vehicle to the given star (degrees).
BODY CONIC	A two part orbit description where the first part (BODY) states the celestial body around which the elements block has been computed and the second part (CONIC) states the type of conic characterizing the vehicle trajectory.
CRIP	Circular range from the current vehicle position to the analytical instantaneous impact point (nautical miles).
CSM IS (NOT) VISIBLE	Statement that the CSM is or is not visible from the LEM.
DAZR	Radar azimuth rate (degrees per second).
DCA	Distance of closest approach of the vehicle to the center of the target body (feet).
DECL	Declination, the angle between the radius vector and the earth's equatorial plane, positive northward (degrees).
DELI	LEM ascent plane change requirement; the minimum great circle arc distance from the CSM parking orbit plane to the landing (launch) site, measured positive to the north (degrees). See Figure 4.
DELR	Radar elevation rate (degrees per second).
DLIN	Declination (latitude) of the velocity vector from infinity, in the selenocentric (selenographic) coordinate system, positive northward (degrees).
DPR	This quantity is not being computed.
DQR	This quantity is not being computed.
DRG	Axial aerodynamic force on the vehicle (pounds).
DRCL	Time derivative of the slant range measured in the CSM centered relative coordinate system, positive increasing (feet per second). See Figure 2.

* See Figure 3.

SYMBOL	DEFINITION
DRGR	Time derivative of the slant range from the radar site to the vehicle (feet per second).
DUL DVL DWL	Components of the vehicle velocity vector measured in the topocentric launch site fixed coordinate system (feet per second).
DVI	Magnitude of all accelerations except gravity (feet per second per second).
DVV	Magnitude of the total acceleration vector (feet per second per second).
DWT	Total weight flow rate (pounds per second).
EARTH IS (NOT) VISIBLE	Statement that the earth is or is not visible from the vehicle.
ECC	Osculating orbital eccentricity.
ECL	Elevation angle of the relative range vector from the CSM to the LEM, measured in the XCL-ZCL plane, i. e. , the orbit plane of the CSM, clockwise from the positive ZCL axis to the projection of the relative range vector upon the XCL-ZCL plane (degrees). See Figure 2.
(NOT) ECLIPSED	Statement that the vehicle either is or is not eclipsed by the primary body. (test procedure for earth eclipse: 1. If XP is positive, vehicle cannot be eclipsed, and the test is concluded. 2. If XP is negative, vehicle may be eclipsed, and the test proceeds to an examination of YP. 3. If XP is negative and YP is positive, vehicle is not eclipsed. 4. If XP is negative and YP is negative, vehicle is eclipsed).
ECSM	Elevation angle of the relative range vector from the LEM to the CSM with respect to the sensible horizon of the LEM, positive upward (degrees).
ELAT	Geocentric latitude of the vehicle, measured from the plane of the ecliptic, positive when the vehicle is on the same side of the ecliptic plane as the ecliptic north pole, and negative when on the opposite side (degrees).

SYMBOL	DEFINITION
ELK	Earth look angle, i.e., the angle between the positive roll axis of the vehicle and the geocentric radius vector to the vehicle (degrees).
ELON	Geocentric longitude of the vehicle, measured in the plane of the ecliptic, positive counterclockwise from the Y' axis, i. e. , from the axis lying in the plane of the ecliptic and forming an orthogonal coordinate system with the ecliptic north polar axis, Z', and the X' axis which extends positively along the vector from the geocenter to the heliocenter (degrees).
ELR	Elevation angle of the vehicle from the radar site measured from the astronomic horizontal, positive upward (degrees).
ELS	Elevation angle of the sun with respect to the local horizon of the landing site, positive upward (degrees).
EMV	Earth-moon-vehicle angle, i.e., the angle subtended at the moon by the vectors from the moon to the earth and vehicle (degrees).
EVST	Earth-vehicle-star angle, i.e., the angle subtended at the vehicle by the radius vectors from the vehicle to the given star and to the geocenter (degrees).
ETX ETY ETZ	Components of a unit vector along the vehicle positive yaw axis in the X, Y, Z directions respectively, measured in the Greenwich inertial coordinate system.
EVS	Earth-vehicle-sun angle, i. e. , the angle subtended at the vehicle by the vectors from the vehicle to the sun and earth (degrees).
FN	Magnitude of the aerodynamic forces normal to the vehicle roll axis (pounds).
FPVA	Flight path angle, measured positive upward from the local horizontal to the relative velocity vector (degrees).
FPVI	Flight path angle, measured positive upward from the local horizontal to the inertial velocity vector (degrees).
IDVL	Ideal velocity per primary stage (feet per second).

SYMBOL	DEFINITION
INCL	Osculating orbital inclination with respect to the reference equatorial plane of the specific coordinate system (degrees).
LAP	Angle between the vehicle roll axis and the radar-to-vehicle line-of-sight projected on the pitch plane, positive if the vehicle nose is above the line-of-sight (degrees).
LAPP	This quantity is not being computed.
LAY	Angle between the vehicle roll axis and the radar-to-vehicle line-of-sight projected on the yaw plane, positive if the vehicle nose is to the right of the line-of-sight (degrees).
LFTN	Aerodynamic force normal to drag and in the plane of the radius and relative velocity vectors (pounds).
LFTL	Aerodynamic force in direction defined by cross product of normal force vector into the drag vector (pounds).
LONE	Selenographic longitude of the earth (degrees).
LONI	Longitude of the analytical instantaneous impact point measured positive eastward (negative westward) from the zero meridian in the equatorial plane of the reference body (degrees).
LONM*	Longitude of the vehicle position measured positive eastward (negative westward) from the zero meridian in the equatorial plane of the reference body (degrees).
LONS	Selenographic longitude of the sun (degrees).
LTDE	Selenographic latitude of the earth (degrees).
LTDI	Geodetic (selenographic) latitude of the analytical instantaneous impact point (degrees).
LTDM**	Geodetic (selenographic) latitude of the vehicle position, measured positive northward (degrees).
MA	Mean anomaly (degrees).
MACH	Mach number.

* In selenocentric print block equivalent to right ascension.
** In selenocentric print block equivalent to the declination.

SYMBOL	DEFINITION
MEV	Moon-earth-vehicle angle, i. e., the angle subtended at the earth by the vectors from the earth to the moon and vehicle (degrees).
MVST	Moon-vehicle-star angle, i.e., the angle subtended at the vehicle by the radius vectors from the vehicle to the given star and to the selenocenter (degrees).
MVE	Moon-vehicle-earth angle, i. e., the angle subtended at the vehicle by the vectors from the vehicle to the moon and earth (degrees).
OPCL	Out-of-plane angle of the relative range vector from the CSM to the LEM with respect to the XCL-ZCL plane, i. e., with respect to the orbit plane of the CSM, measured from the orbit plane to the relative range vector, positive when relative range vector lies on the same side of the orbit plane as the positive YCL axis (degrees). See Figure 2.
PAT	Vehicle pitch attitude, measured in the topocentric inertial PXG-PYG-PZG coordinate system, from the positive PZG axis to the projection of the vehicle's roll axis onto the PXG-PZG plane, positive in the direction of the launch azimuth (degrees).
PERD	Keplerian orbital period, derived from osculating semi-major axis (minutes).
PERG	Perifocal altitude above the reference ellipsoid of the central body along the radius vector to the perifocus (nautical miles).
PICH	Rate of rotation about the pitch axis, positive downward (degrees per second). See Figure 1.
PXG PYG PZG	Components of the vehicle position in the topocentric inertial coordinate system (feet).
Q	Dynamic pressure (pounds per square foot).
QAL	Product of the dynamic pressure and the total angle of attack (degree-pounds per square foot).
R	Magnitude of the radius vector (feet).

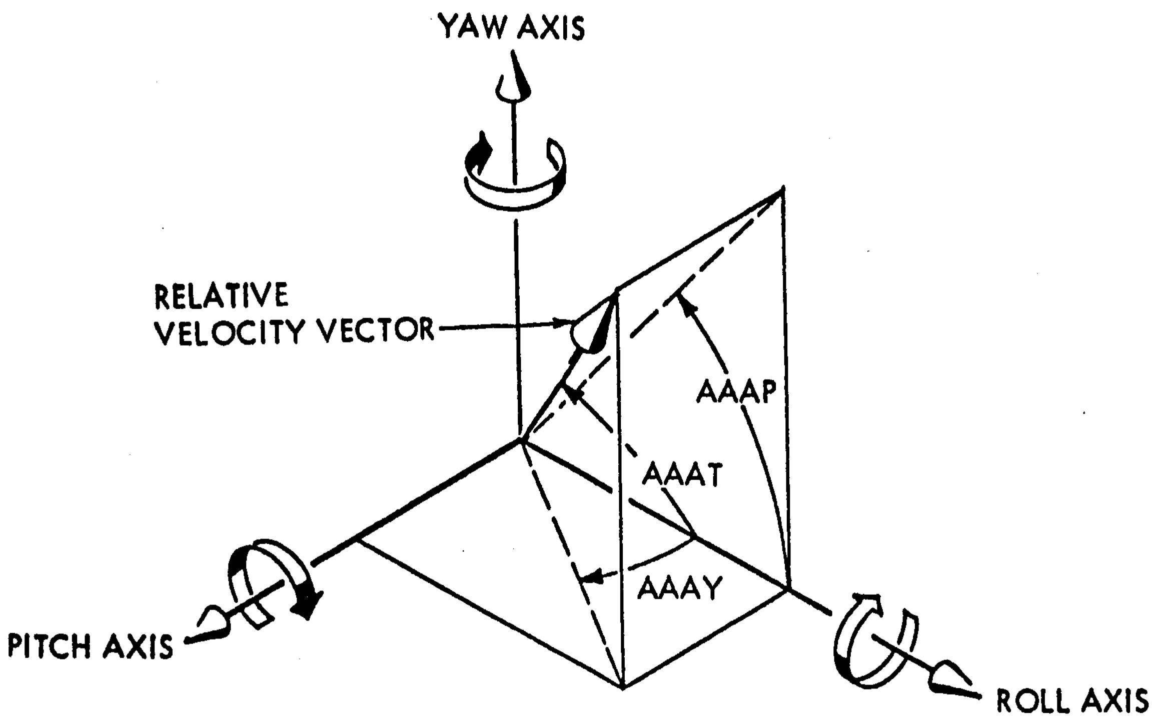
SYMBOL	DEFINITION
RANG	Distance from the launch (target) site to the vehicle position projected to the surface of the sphere (nautical miles).
RASC	Right ascension of the vehicle, positive eastward (degrees).
RAT	Vehicle roll attitude, measured in the topocentric inertial PXG-PYG-PZG coordinate system, from the negative PXG axis to the projection of the vehicle's yaw axis onto the PXG-PYG plane, positive to the left of the downrange direction (degrees).
RCL	Magnitude of the range vector from the CSM to the LEM, measured in the CSM centered relative coordinate system (feet). See Figure 2.
RDR nn	The last two characters of this symbol state the radar number and are followed by a description of the radar site.
RGR	Slant range from the radar site to the vehicle (feet).
RLA1	Angle between the vehicle roll axis and the radar line-of-sight(degrees).
RLA2	Angle between the vehicle yaw axis and the radar line-of-sight projected on the roll plane. From the rear of the missile the angle is measured clockwise from the positive yaw axis (degrees).
RLAT	Roll attitude. Angle between the projection of the inertial position vector onto the roll plane and the positive yaw axis, positive 0 to 180 if the projection is clockwise from yaw axis, negative 0 to 180 if counterclockwise (degrees).
ROLL	Rate of rotation about the roll axis, positive counterclockwise (degrees per second). See Figure 1.
SEM	Sun-earth-moon angle, i. e., the angle subtended at the earth by the vectors from the earth to the sun and moon (degrees).
SLK	Sun look angle, i. e., the angle between the positive roll axis of the vehicle and the heliocentric radius vector to the vehicle (degrees).

SYMBOL	DEFINITION
SME	Sun-moon-earth angle, i. e., the angle subtended at the moon by the vectors from the moon to the earth and sun (degrees).
SVST	Sun-vehicle-star angle, i.e., the angle subtended at the vehicle by the radius vectors from the vehicle to the given star and to the heliocenter (degrees).
SS	Speed of sound (feet per second).
STAR	Name of given star.
SVM	Sun-vehicle-moon angle, i. e., the angle subtended at the vehicle by the vectors from the vehicle to the sun and moon (degrees).
T	Present time, specified in four ways: first, as day, month, year, hour, minute, and second, Universal Time; second, as the time interval (TMST) from liftoff, in seconds; third, as Julian Date (J. D.); and fourth, as days, hours, and minutes from liftoff.
TA	True anomaly (degrees).
TCA	Time interval from the time of injection into the transfer orbit to the time at which the vehicle reaches its point of closest approach to the center of the target body(minutes).
TFFI	Angle between the selenocentric radius vector to the vehicle and the vector which passes through the selenocenter and is parallel to the velocity vector from infinity, V_∞ (degrees).
THIN	Angle between the selenocentric radius vector to perifocus of the transfer orbit and the vector which passes through the selenocenter and is parallel to the velocity vector from infinity, V_∞ (degrees).
TIMP	Time interval from the current time to the analytical instantaneous impact (seconds).
TLK	Target look angle, i. e., the angle between the positive roll axis of the vehicle and the target-centered radius vector to the vehicle (degrees).

SYMBOL	DEFINITION
TMFL	Time of flight, i. e., the time interval from injection into the transfer orbit to the present time (minutes).
TPSE	Total impulse per stage (pound seconds).
UL VL WL	Components of the vehicle position vector measured in the topocentric launch site fixed coordinate system (feet).
VA	Magnitude of the relative velocity vector, measured in a body fixed coordinate system with the origin at the center of the reference body and including the effects of any sensible atmosphere simulated in the system.
VAPG	Predicted velocity at apofocus (feet per second).
VAT	Tangential component of relative velocity vector (feet per second).
VEDC (VSDC, VTDG)	Declination of the earth (sun, target) with respect to the vehicle centered coordinate system, i. e., the coordinate system which is congruent to the geocentric equatorial inertial coordinate system (referenced to true vernal equinox of date), but in which the origin has been translated to the center of the vehicle (degrees).
VEHICLE IS (NOT) ECLIPSED	Statement that the vehicle is or is not within the umbral shadow cone of the moon.
VERA (VSRA, VTRA)	Right ascension of the earth (sun, target) with respect to the above defined vehicle centered coordinate system (degrees).
VES	Vehicle-earth-sun angle, i. e., the angle subtended at the earth by the vectors from the earth to the vehicle and sun (degrees).
VI	Magnitude of the inertial velocity vector (feet per second).
VINF	Magnitude of the velocity vector from infinity, V_∞, in the selenocentric (selenographic) coordinate system (feet per second).
VIR	Radial component of the inertial velocity vector (feet per second).

SYMBOL	DEFINITION
VIRE	Inertial velocity at the re-entry altitude on the analytical prediction trajectory (feet per second).
(NOT) VISIBLE	Statement that the vehicle is or is not visible to the earth, i. e., is or is not occulted by the moon.
VISN	Sensed velocity, $\int DVI \cdot dt$ (feet per second).
VIT	Tangential component of inertial velocity vector (feet per second).
VLGR	Velocity loss due to gravity (feet per second).
VLML	Velocity loss due to thrust misalignment with respect to the inertial velocity vector (feet per second).
VMS	Vehicle-moon-sun angle, i. e., the angle subtended at the moon by the vectors from the moon to the vehicle and the sun (degrees).
VPER	Predicted velocity at perifocus (feet per second).
VVST	Velocity vector vehicle angle, i.e., the angle measured from the inertial velocity vector of the vehicle to the radius vector from the vehicle to the given star (degrees).
VVEN	Vis viva energy, twice the total energy per unit mass of the vehicle (feet squared per second squared).
VX VY VZ	Components of the inertial velocity vector (feet per second).
VXCL VYCL VZCL	Coordinates of LEM velocity, measured in the CSM centered relative coordinate system (feet). See Figure 2.
VXG VYG VZG	Components of the velocity vector in the topocentric inertial coordinate system (feet per second).
WT	Total vehicle weight (pounds).

SYMBOL	DEFINITION
XCL YCL ZCL	Coordinates of LEM position, measured in the CSM centered relative coordinate system (feet). See Figure 2.
XIX XIY XIZ	Components of a unit vector along the vehicle positive roll axis in X, Y, Z directions respectively, measured in the Greenwich inertial coordinate system.
XMN YMN ZMN	Components of the moon's position vector in the geocentric inertial coordinate system (feet).
XP	The component of the geocentric radius vector to the vehicle along the earth-sun line, i. e. , the component along the vector from geocenter to heliocenter, positive when the vehicle is between the earth and sun, and negative when the vehicle is on the opposite side of the earth from the sun (earth radii).
YAT	Vehicle yaw attitude, measured in the topocentric inertial PXG-PYG-PZG coordinate system, from the negative PYG axis to the projection of the vehicle's pitch axis onto the PYG-PZG plane, negative in the direction of the launch vertical (degrees).
YAW	Rate of rotation about the yaw axis, positive to the right (degrees per second). See Figure 1.
YP	Distance of the vehicle from the umbra of the primary body, measured along a normal to the axis of the umbral cone, positive when the vehicle is outside the umbral cone (earth radii). (Note: In relation to the determination as to whether the vehicle is eclipsed, the sign of YP is meaningful only when XP is negative.)



NOTE: AAAP AND AAAY SHOWN IN THIS DIAGRAM ARE NEGATIVE; AAAT IS UNSIGNED.

Figure 1. Vehicle Fixed Coordinate System

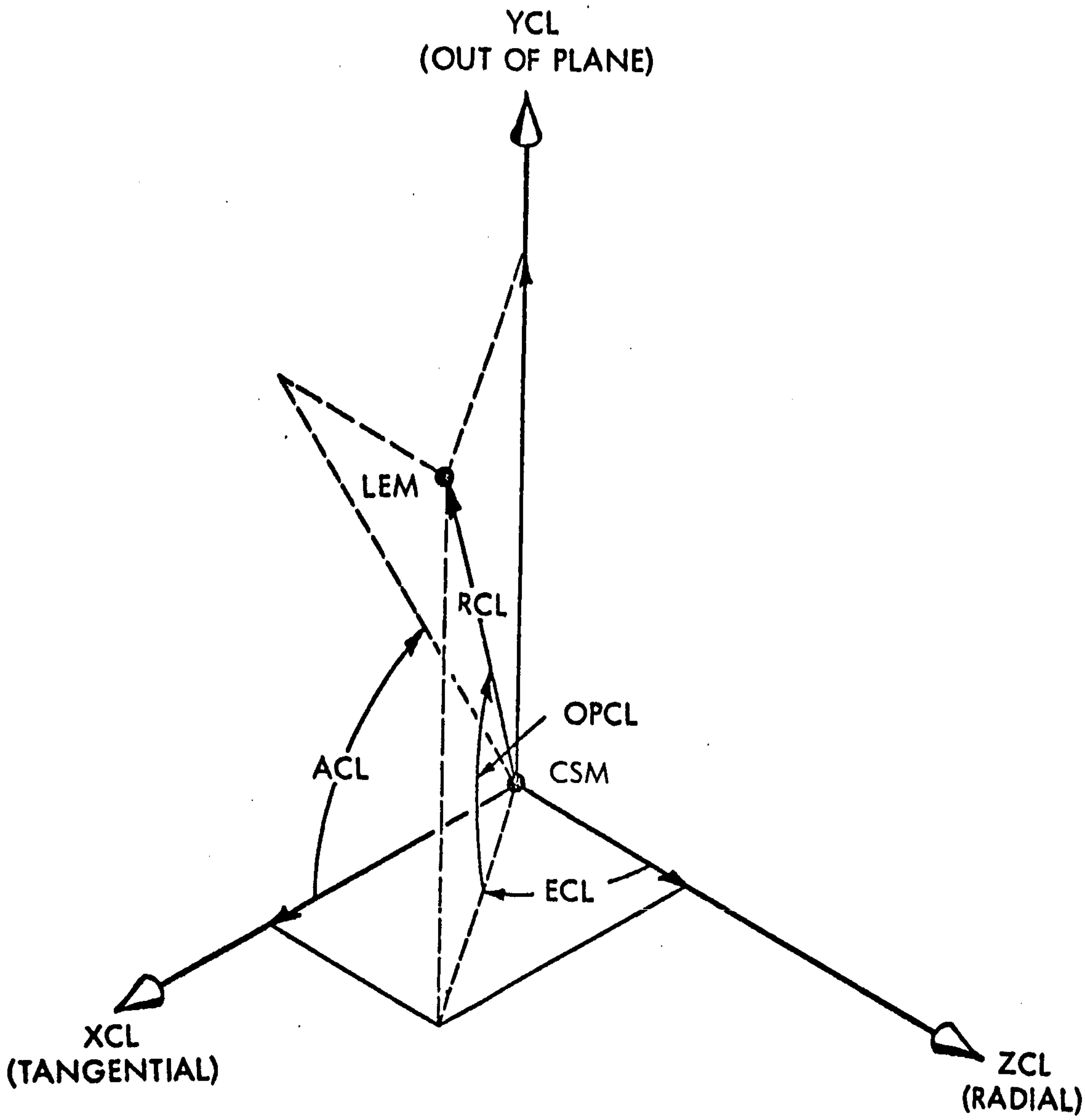


Figure 2. CSM Centered Relative Coordinate System

NOTE: THE S AXIS IS PARALLEL TO THE INCOMING HYPERBOLIC ASYMPTOTE.

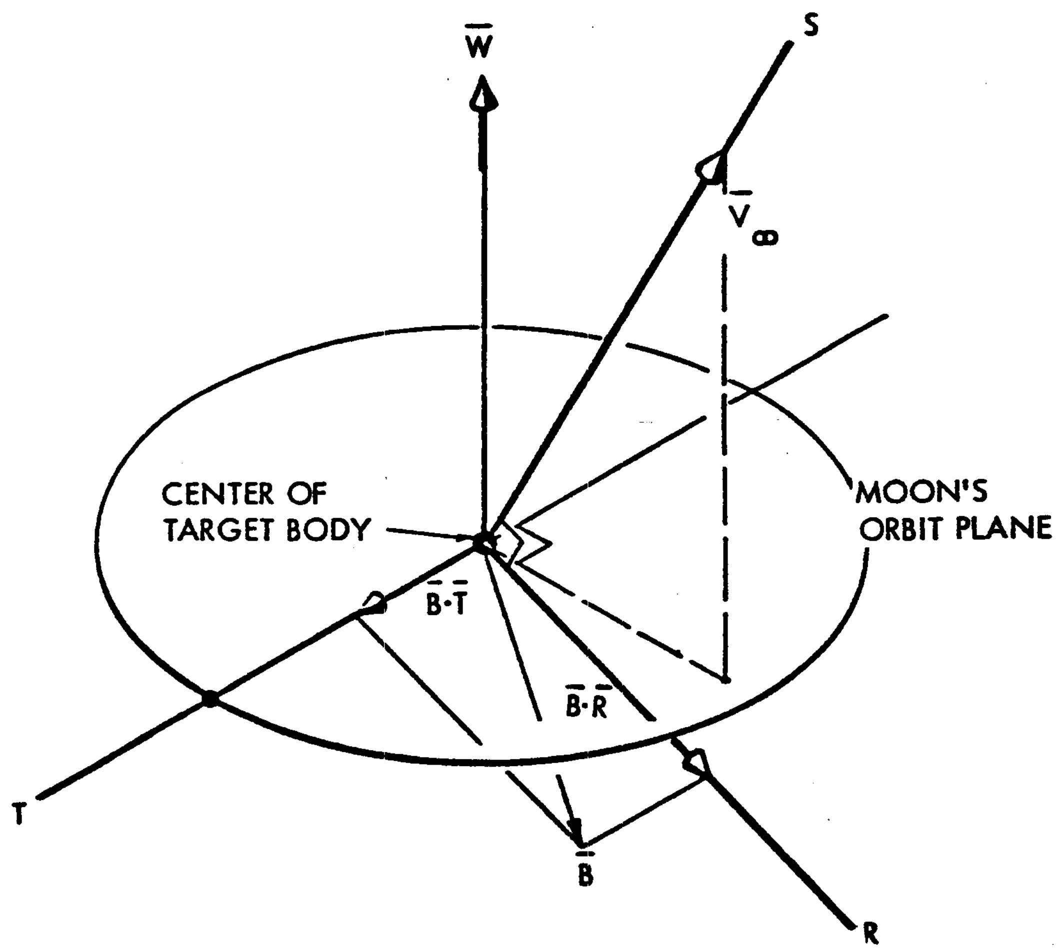


Figure 3. Target Centered S-T-R Coordinate System

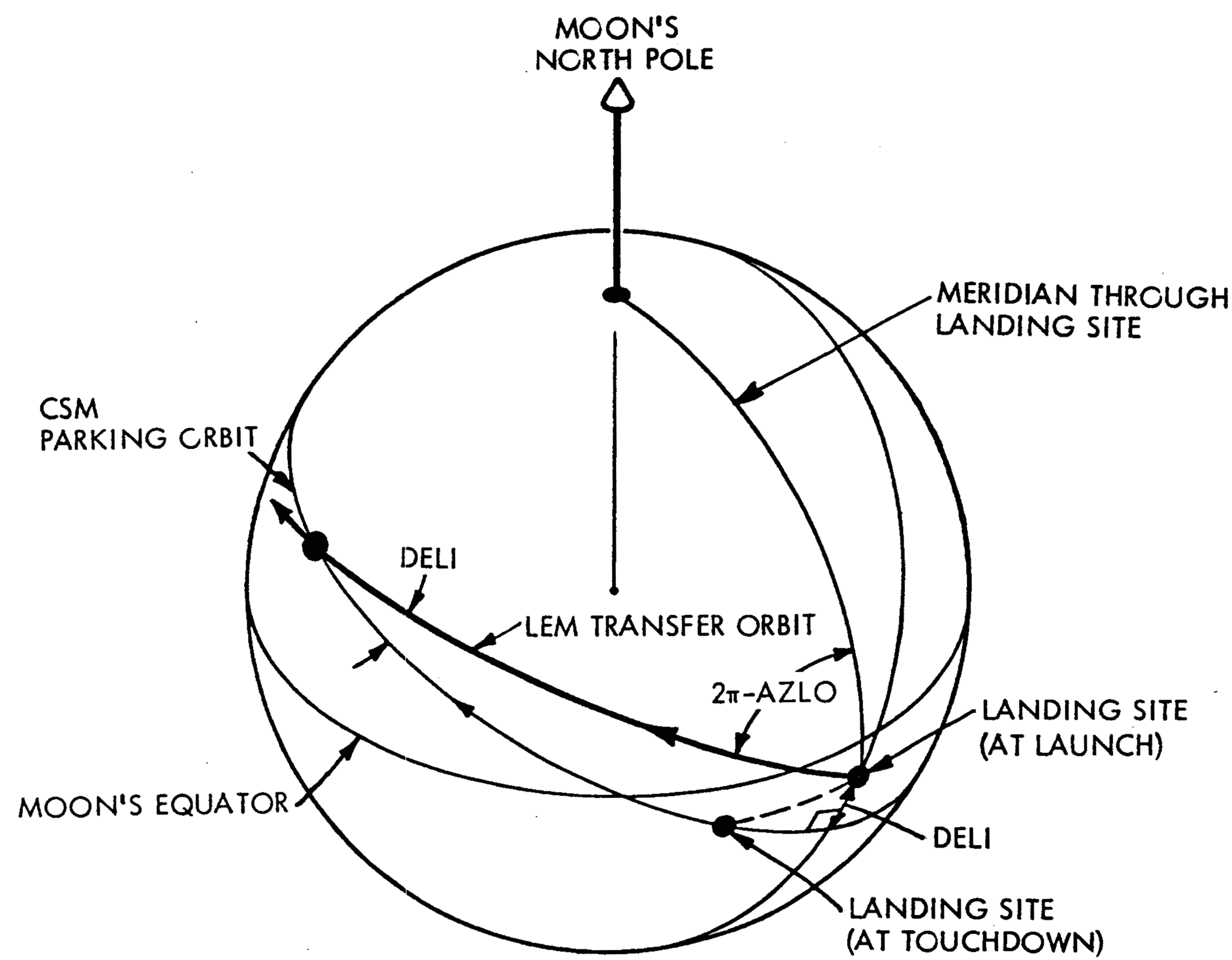


Figure 4. LEM Ascent Geometry